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This Navy Grant supports research focused on sea surface flow regimes and their analyses. The objective is establishment of an ongoing archive that is gathered from remotely-sensed imagery and drifter trajectories, and applied in studies of circulation on the Texas-Louisiana Shelf (TLS). The geographic location has been chosen because of the wealth of archival, coincident *in situ* Eulerian current meter, Lagrangian drifter, and hydrographic observations, as well as visible, infrared, and microwave remote sensing data. All are relevant to the type of problems and investigations presently encountered by the Navy. As well, there are continuing TLS observations of similar diversity and coverage. There are wide ranges of atmospheric, riverine, estuarine and deep water dynamic forcing and associated responses present over a variety of bottom topography and shelf-width environments with diverse shoreline configurations. These characteristics provide an abundant arena for research and development of systems pertinent to Navy coastal and nearshore requirements and operations.

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Scientific Officer, Code 7340
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Naval Research Laboratory
Stennis Space Center, MS 39529-5004

Subj: Final Technical Letter Report under Grant No. N00173-98-1-G901, "Analysis of Sea Surface Flow Patterns," 17 December 1997 through 16 December 1998

Dear Dr. Smith:

Enclosed with this cover letter is a report submitted as fulfillment for the subject grant's terms. The attached report meets the requirements for the final technical report as well as the monthly reports requirement.

The report provides results of the current vector distributions that were analyzed for Naval Research Laboratory. Over the one year term of the grant, analyses of approximately two vector fields were accomplished. The pertinent information with reference to the Texas Current jet off Freeport was extracted each month for an ongoing statistical evaluation that was completed in mid-August.

The final report summarizes this demonstration of the use of the Gulf current vector archive and presents a tabular representation of the jet's characteristics.

We anticipate and look forward to further work with the interactive procedure for extracting flow distributions and the development of additional kinematic representations of flow characteristics for the Texas-Louisiana Shelf and Slope.

Sincerely,

Andrew C. Vastano
Research Fellow

Attachment

TL-SG-98-13

Analysis of Sea Surface Patterns
Grant N00173-98-1-G901
FINAL REPORT

19990526 003

Date : 31 August 1998

To: Dr. Walter Smith
Code 7340
Remote Sensing Applications Branch
Naval Research Laboratory
Stennis Space Center

From : Dr. Andrew C. Vastano
Applied Research Laboratories
The University of Texas at Austin
Austin, Texas

Introduction

This Navy Grant supports research focused on sea surface flow regimes and their analyses. The objective is establishment of an ongoing archive that is gathered from remotely-sensed imagery and drifter trajectories, and applied in studies of circulation on the Texas-Louisiana Shelf (TLS). The geographic location has been chosen because of the wealth of archival, coincident *in situ* Eulerian current meter, Lagrangian drifter, and hydrographic observations, as well as visible, infrared, and microwave remote sensing data. All are relevant to the type of problems and investigations presently encountered by the Navy. As well, there are continuing TLS observations of similar diversity and coverage. There are wide ranges of atmospheric, riverine, estuarine and deep water dynamic forcing and associated responses present over a variety of bottom topography and shelf-width environments with diverse shoreline configurations. These characteristics provide an abundant arena for research and development of systems pertinent to Navy coastal and nearshore requirements and operations.

The work reported herein examines an initial suite of sequential AVHRR imagery, derivative flow fields, and drifter paths that are part of the archive. This report's results represent one example of what a comprehensive analysis scheme can do to characterize a coastal current regime. It is a simple application of an image/flow pattern/drifter archive that serves to demonstrate the potential for future regional and local studies of surface motion and its relationship to environmental factors.

The individual vector observations that compose the flow regimes were obtained with the intention of resolving TLS fronts and eddies that exist at spatial scales of 10 to 15 km. This horizontal scale is a local Rossby radius of deformation, the first TLS baroclinic radius of deformation, and was evaluated for an average depth of 20 m. In boundary regions, such a length can be used to identify physical mechanisms that should be considered in model predictions of transient response. It is a length measure at which rotation becomes as effective a physical mechanism as buoyancy in the evolution of local currents, fronts, and eddies (Gill, 1982). That is, at scales ≥ 10- 15 km, a TLS surface anomaly or surface discontinuity will tend to equally disperse by rotary motion and turbulence as by the leveling influence of gravity.

The Texas-Louisiana Shelf is undoubedly a convenient region for the oceanographic studies and most recently received research attention in the LATEX project of the federal Mineral Managment Service and the TEXFLEX and TEXFLOW projects supported by the State of Texas. These projects have gathered a wealth of *in situ* information that can support new understandings of coastal physical structure and dynamics. One common focus was the general relationship between forcing and response (Vastano, 1997). Beyond their significance to commercial, federal, and state public concerns, the TLS archives and presently ongoing augmentation of data bases have a major potential for research into warfighting support problems applicable to remote assessments in denied access circumstances. The prevalence of strong, rapid episodic forcing and the generation of both organized regimes and turbulent cascades in shallow waters give reseach efforts cost effective opportunities to develop and evaluate Navy-relevant observation and prediction systems.

The examination herein of surface motion utilizes flow pattern results obtained with an interactive visualization technique (Vastano and Borders, 1984; Vastano and Reid, 1985) and infrared imagery obtained with NOAA satellite AVHRR instrumentation. Trained analysts provide appropriate pattern recognition skills as well as the required background in surface circulation dynamics. This has produced a research capability with the highest accuracy now available for remote satellite flow analyses (Vastano, 1996). The images selected for this analysis are from the 1984-94 time interval and are weighted by the predominant availablity of imagery in the Fall through Spring seasons.

The sea surface drifter data are from the TEXFLEX project archives. The observations were acquired from Horizon Marine FHD-A drifters by Argos using the Data Collection System aboard the same NOAA platforms that gather AVHRR infrared imagery. Drogued to a depth of 2.7 m, the drifters provided six to ten useful position estimates each day with an accuracy such that sixty-eight percent of the positions are within 350 meters of the actual

position (Swenson and Shaw, 1990). Barron (1994) has used TEXFLEX drifter arrays to calibrate and verify a single layer, quasi-geostrophic TLS predictive model.

In regard to the accuracy of image-derived flow, a compilation of remote determination accuracies has been made for experiments in which investigators contributed their own *in situ* verification data. To insure suitable comparisons, each data base was treated with the same complex regression scheme (Vastano, 1996). *In situ* measures of flow velocity were made with drifters, acoustic doppler current profilers, geostrophic current calculations, and current meters. Of the results analyzed, interactive visualization (IV) accuracies were much better than those achieved by maximum cross correlation (MCC) applications. The comparison for Vastano and Barron's (1994) IV study produced the highest accuracy with 22 paired *in situ* and remote vector estimates. The flow speed estimates were evaluated in the range of 14 to 60 cm s^{-1}, reckoned using apparent surface heat anomaly displacements over a 23.9 hr image separation with verification data from surface-drogued drifters. The standard error attained in estimating *in situ* from remote speeds was 6 cm s^{-1} and the mean difference in direction of remote relative to *in situ* vectors was 2 degrees. The percentage of the in situ vector variance ex-plained by a linear relationship with the remote vectors was 94 percent. The least accurate MCC procedure utilized ADCP data from the shallowest, that is 28 m, depth bin. The study produced regression estimate errors of 28 cm s^{-1} and 68 degrees, and an explantion of variance at 9 percent.

The image and flow methods applied by Vastano and Barron have been used to study surface motion from the longitude of Lake Charles to the lati-tude of lower South Padre Island. On seasonal time scales, this segment of the Texas-Louisiana Shelf is marked by a slowly varying, mean flow pattern that trends westward and then southwestward for approximately nine months of the year, September to May, and a reverse pattern from June through August. Vastano, et al. (1995) demonstrated that variability induced by strong seaward or alongshore atmospheric frontal passages could, at any time of the year, produce current responses that greatly enhance, suppress, and, on occasion, completely reverse the direction of an established nearshore regime. The twenty-three flow fields and the drifter trajectories identified for consideration during the Grant are available to the Navy sponsor.

Investigation of a Nearshore Shallow Water Regime

Project investigations of patterns that contain nearshore transients were centered on the southwestward and northeastward regimes that arise along the Texas coastline, off Freeport. The objective is an estimate of their

physical attributes. Two examples of such patterns were presented by Vastano, et al. (1995) and the phenomena referred to as the Texas Current. The Current takes on the aspect of a strong episodic southwest flow (SWTC) of limited duration that can affect the entire length of the Texas coastline during nine months of the year, September through May. The converse expression of the Texas Current, a northeastward transient (NETC), often occurs during the three summer months, that is, June through August, and, on the basis of a small sample, is usually closer to shore than its counterpart.

The characteristics of the Current have been drawn from twelve patterns, ten SWTC and two NETC during 1992-94. Other estimates were possible that afforded only partial coverage of the region and these were set aside because the alongshore extent of the regime could not be verified. Table 1 provides estimates of the Texas Current location, off-shore distance, speeds and acceleration intervals. Note that these measures are not made with a statistically significant sample size.

Texas Current off Freeport, Texas	SWTC	NETC
mean latitude (°N)	28.9 ±0.2	29.0
mean longitude (°W)	95.1 ±0.3	95.1
cross-shelf distance offshore (km)	19 ±8	10
water depth (m)	20 ±3	16
pre-event 24-h mean speed (cm/sec)	21 ±6	18
mean surge 24-h speed (cm/sec)	89 ±18	39
mean surge highest 6-h speed (cm/sec)	112 ±9	43
post-event 24-h mean speed (cm/sec)	21 ±8	22
acceleration to peak speed interval (h)	38 ±9	42
deceleration to pre-event speed interval (h)	36 ±19	12

Table 1. Estimates of Texas Current Physical Characteristics

The Table 1 values collectively indicate jet-like and strong velocity transients can rapidly develop nearshore. A composite set of vectors from imagery (8) and drifter sources (3) have been treated for SWTC means and standard deviations. The composite was formed on the basis of the small standard

error in agreement between coincident, independent *in situ* versus remote estimates. There is caveat. The examination of the percentage of *in situ* variance explained by remote estimates was carried out for 24 h average speeds in the range of 0-60 cm s^{-1}. So the use of several estimates nearly twice those in the verification study (Vastano and Barron, 1994) clearly implies that care should be taken in any physical interpretations. The results are also less than comprehensive in terms of the number of cases and the coverage of environmental influences. However, the purpose of the analysis and the Table are demonstrations that useful environmental assessments are possible. This Current evaluation indicates the potential contributions of remote data bases when direct access is denied.

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